ABSTRACT

The paper presents different aspects of phased array ultrasonic technology (PAUT) recently applied to different turbine components on three major OPG sites:

- Darlington: GEC Alstom/ABB low-pressure rotor steeple and steam chest outlet welds
- Pickering B: Siemens/Parsons: relief valve pins
- Nanticoke GS: HP, IP rotor grooves, main steam ESV and BFPT valves.

Different aspects of PAUT commissioning, sizing capability and field applications are presented and discussed. Examples of crack height comparison between fracture mechanics and PAUT are also included. PAUT is undersizing the SCC and fatigue cracks by 0.5 to 1.2 mm. Based on high redundancy, diversity and validation of PAUT, all three sites decided to employ PAUT as a reliable tool for the duty cycle management and outage planning.

DARLINGTON NGS PAUT APPLICATIONS

PAUT was applied to DNGS since 1997 (ref.1-4). Stress corrosion cracks and high-cycle fatigue cracks due to fretting and loading were found in rotor steeple and blade root of row 0 – GEC Alstom 900-MW low-pressure turbine (see Figure 1).

Figure 1 - Crack location, PAUT data plotting for L-0 Blade (left) and L-0 rotor steeple (right)

OEM (GEC Alstom) decided to redesign the L-0 blade by eliminating the upper hook. A 4-unit de-blading and re-blading process was set in place. IMCS was asked to extend the inspection scope for L-0 rotor steeple to all 5 hooks over all their length (450 mm) on both sides (concave and convex), and to perform the in-situ scan with the blade carrier in place. Specific scanners, reference blocks, capability demo blocks and probes were developed and commissioned during 2007-2008 period. Figure 2 illustrates the calibration on concave inlet side (350-450 mm region) on three targets on each hook. The targets are elliptical EDM notches with height between 0.5 mm and 2 mm. Their length is 9 mm and 6 mm (middle one).
Figure 2 - Example of calibration display of three targets on each hook for inlet concave inspection with blade carrier in place

During the feasibility study and capability demonstration was proven the system is capable to detect and size targets as small as 7 mm x 0.7 and 6 mm x 1 mm on hook 5 (depth z=117 mm!) – see Figure 3.

Figure 3 - Example of detection capability assessment for hook 5 on complex EDM notch of 7 mm x 0.7 mm

IMS developed a defense-in-depth PAUT reliability structure based on validation, redundancy and diversity (ref.5 and 6). Figure 4 represents an example of additional confirmation technique using semi-lateral scanning and a special-design wedge for inlet convex side-hook 5.

Figure 4 - Example of defect confirmation and sizing for hook 5 - concave inlet. Top right – no defect. Bottom right – defect
The system and techniques are capable to distinguish between corrosion pits and cracks. Axial resolution is between 0.3 mm to 0.5 mm, depending on defect depth and probe frequency (see Fig. 5).

Figure 5 - Example of S-scan display of 10 ‘corrosion’ pits of 0.5 mm spaced apart 0.5 mm located on hook 1; left – Omniscan; right-Focus LT PAUT machines

Significant confirmation and sizing improvements were achieved for PAUT applications on L-1 steeple, namely in specular detection in the first 10-15 mm on hook 1 and 3 (see Figure 6). Targets as small as 4 mm x 1.5 mm are reliable detected and sized.

Figure 6 - Example of defect confirmation and sizing using a customized LPAP under the blades

Sizing capability of T-waves and L-waves probes was assess on a as-built L-1 steeple with 2 SCC-like EDM notches located at z = 35-47 mm (see Figure 7).

Figure 7 - Example of diversity for sizing crack-like EDM notches on L-1 steeple by: L-waves (left) and T-waves (right).
In some special situation, the station is asking the PAUT team to size, plot and report cracks in components under repairing process. The scope is to assess the crack height and its orientation, to avoid a costly repair and post-weld heat treatment on site. Due to a large variety of miniature and sub-miniature phased array probes, the team succeeded to help in real time the maintenance outage crew in sizing and plotting cracks in steam chest outlet welds (see Figure 8), saving station 4-5 outage days.

![Figure 8 - Example of crack sizing and 3-D plotting for steam chest outlet weld under exaction.](image)

**PICKERING B NGS PAUT APPLICATION**

The pins of relief valves (called butterfly intercept valves) developed shear fatigue cracks, almost 360°, with height between 1 mm and 7 mm. Checking the pins by conventional UT requires the valve to be dismantled and opened (see Figure 9), so the probe should have access only from the near side of the pin. There are four valves / LP and eight pins / valve.

![Figure 9 - Relief valve – dismantled (right) and the pins require in-situ PAUT. Bottom: crack location and UT path for in-situ inspection.](image)
PAUT team was asked to develop an in-situ technique for pin crack detection (h=1 mm) and sizing (h=5 mm). The feasibility study identified the following issues:

- Narrow pin diameter
- Long UT path for far-end (z = 222 mm-300 mm)
- Machining hole for pin holding – centered and deep on both sides
- Big nut on top of the pin
- Field access is performed through a confine-space pipe of 42”.

Near side inspection was not a challenge for PAUT. Far side detection and sizing was based on mode-converted S-and B-scan displays (see Figure 10).

![Figure 10 - Example of detection of 8 x 1 mm EDM notch on far side of the pin.](image)

An in-situ tool was commissioned and the system is now in operation for more than 3 years (see Figure 11). PNGS B is saving about 700 h / outage.

![Figure 11 - Example of detection and sizing, data plotting and field tool for in-situ inspection.](image)
NANTICOKE GS PAUT APPLICATIONS

OPEX and ECA led to the concept: living with cracks! It is a world common practice for NDT service provider to size cracks in ESV and GV in thermal stations (see Figure 12).

![Figure 12 - Example of crack location in ESV and GV.](image)

The life assessment group requires reliable UT data for cut/repair/operate decision. PAUT team was asked to develop in-situ techniques to inspect three types of valves in thermal station. The accuracy in sizing: ± 1 mm, with crack height > 5 mm. probes, techniques, ray-tracing, simulation and 3-D data plotting were developed to fulfill the tasks. PAUT procedures were in the field in fall 2007. Monitoring inspections were performed during 2008-2010 period. Examples of PAUT results and data plotting are presented in Figure 13.

![Figure 13 - Example of PAUT results and data comparison with fracture mechanics.](image)
The IP and HP rotors developed cracks in the locking strips and heat relief grooves. PAUT techniques were developed and commissioned in 2008 (see Figure 14). PAUT results were confirmed by cutting and repair (see Figure 15).

Figure 14 - IP rotor (top) and crack location in heat relief groove and locking strip (bottom).

Figure 15 - PAUT results and crack confirmation on IP rotor.
CONCLUSIONS

PAUT field activities applied to three OPG sites demonstrated the reliability of the techniques, regardless the turbine component, inspection technique (specular, diffracted, semi-skew diffracted), UT path (14 mm to 850 mm!) and probe accessibility. Custom-made probes were manufactured by Imasonic-France in different configuration (64-elements pitch 0.4, 0.5, 0.6 mm; integral wedge, high damping). OPG-IMS commissioning process based on validation, redundancy and diversity, back-up by sizing confirmation using replica, fracture mechanics, MP and stereo optical methods led to a reliable life assessment tool used by ECA groups on all three sites. Sizing capability for SCC and fatigue cracks (ref.8) is presented in Figure 16. OPG-IMCS results confirmed the undersizing trend by 0.5-1.2 mm. This trend increases with crack height. As conservative approach in reporting, adding 1 mm is the best way for PAUT-ECA group decision making. Side technique was validated for the following tolerances: \( \Delta \text{length} = \pm 2 \text{ mm}; \ Delta \text{height} = \pm 1.5 \text{ mm and location (depth and index): } \Delta z \text{(depth)} = \pm 2 \text{ mm; } \Delta I \text{(index)} = \pm 2 \text{ mm.} \)

![Figure 16 - Crack height accuracy sizing by PAUT for SCC (left) and fatigue cracks (right).](image)

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